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Earth Model Building With Full-Waveform Inversion - A Case Study From A Shallow Reservoir In The Barents Sea

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Summary

The Wisting field in the southwest Barents Sea is characterized by a shallow reservoir and has a complex geological history. Previous studies in the area showed that imaging the existing surface seismic data in depth with an accurate TTI earth model, and applying compensation for absorption within the migration gave the optimum preservation of AVO for further reservoir characterization. A full-waveform inversion (FWI) model building study was undertaken to derive a high resolution earth model suitable for depth imaging purposes. Anisotropy and absorption quality factor (Q) were derived and calibrated across the available, high quality borehole data in the survey area and incorporated into the starting model. FWI was employed to update the model over the depth range of interest, with reflection tomography used to update below the maximum penetration depth of the FWI. The resulting model is robust, high resolution and consistent with all available well data.

Introduction

The Wisting discovery in the southwest Barents Sea (Figure 1) is a laboratory for geophysical studies due to its shallow reservoir and complex geological history. The reservoir lies as little as 250 m below the seabed in a water depth of approximately 400 m. Our understanding of the acoustic model properties of this discovery was significantly advanced by an integrated study of borehole and seismic measurements performed at a key exploration well in 2014 (Lewis et al., 2016; Veire et al., 2016). A key finding from this study was that optimum amplitude variation with offset (AVO) preservation in the surface seismic data resulted from imaging in the depth domain with accurate vertically transverse isotropy (VTI) model properties and by including compensation for absorption within the imaging itself. The challenge for further imaging work in the Wisting area was to ensure that the information gained about the earth model at the sparse well locations could be incorporated into a seismic-based earth model building workflow. Full-waveform inversion (FWI) from a simple, well-driven starting model was the primary model building tool used for this purpose. It provides high-resolution model updates at and below reservoir level and gives a robust and accurate model for depth imaging.

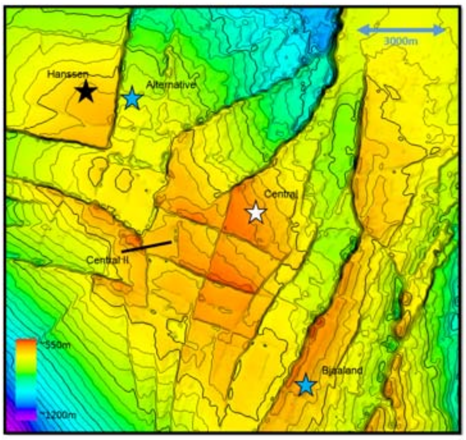

Figure 1 *An illustration of the study area: The Wisting discovery in the Barents Sea.*

Model building methodology

The previous study at the Wisting discovery highlighted several factors that would require careful consideration for depth model building, and these ultimately shaped the model building methodology followed. Firstly, the acquisition geometry of the existing 3D surface seismic data, fast velocities, and high anisotropy near the seabed all contributed to limited near-angle coverage at reservoir level. Secondly, the high anisotropy values determined in the shallow overburden were also required for both accurate reservoir depth determination and for AVO preservation. Finally, the high levels of absorption determined during the previous study also required consideration. Applying incorrect inverse Q compensation has the potential to manifest as velocity error in the inaccurately compensated data. To address the challenges described above, FWI was the model building algorithm of choice. In the manner employed here, FWI uses the early arrival energy in the recorded wavefield, primarily comprised of refracted- and diving-wave energy. Critically for this scenario, the FWI of the early arrival wavefield is not limited by the missing near angles of the reflected wavefield in the shallow. To account for the challenges posed by the variable Q field, we employed Q-FWI (Cheng et al., 2015), where the wavefield propagation and property update accounts for inelastic absorption using the borehole-derived Q property field. We also used the multi-parameter implementation of FWI to update the epsilon property to address any potential spatial variation of anisotropy.

The previous Wisting study and the availability of an extensive suite of borehole measurements at additional wells in the project area formed the basis of the initial model building. Although the well coverage was relatively sparse within the larger model building area, a detailed analysis of the available data showed a high degree of consistency. To further validate the Q-VTI properties accurately determined in the previous study, additional processing of offset well data was performed to derive independent measurements of Q from the zero-offset vertical seismic profile data and Thomsen's gamma from advanced sonic wireline measurements. From all wells, 1D functions were tied to geologic units in the model. These functions, and smooth versions of the borehole measured vertical velocity, were then propagated in a structurally consistent manner through the initial model volume. FWI was performed over two frequency bands, starting from the simple initial model. Adjustive FWI (Jiao et al., 2015) was used initially to first update the low-wavenumber background model, ensuring that the model would be sufficiently accurate to allow us to proceed with least-squares (LS) FWI to build further resolution into the shallow model. After the subsequent LS FWI at the first frequency band, a multi-parameter FWI update for epsilon was performed. A final LS FWI update for velocity was performed at a higher frequency band. The final stages of the model building consisted of additional model updates by means of reflection tomography to update the deepest parts of the model below the depths of penetration of the early arrival wavefield used by the FWI.

Conclusions

FWI was the primary tool used to build a depth model over the Wisting discovery. The methodology followed allowed us to address model building challenges highlighted during the previous study at Wisting and resulted in a 3D Q-tilted transversely isotropic model that was used to image several data sets that cover the Wisting area. The final model resulting from the process is high resolution, highly conformant with structure, and addresses the key requirement to optimize AVO preservation of the final imaged seismic data (Figure 2). In addition, integrating borehole data through the model building process results in a high degree of consistency between the surface seismic and borehole-derived measurements.

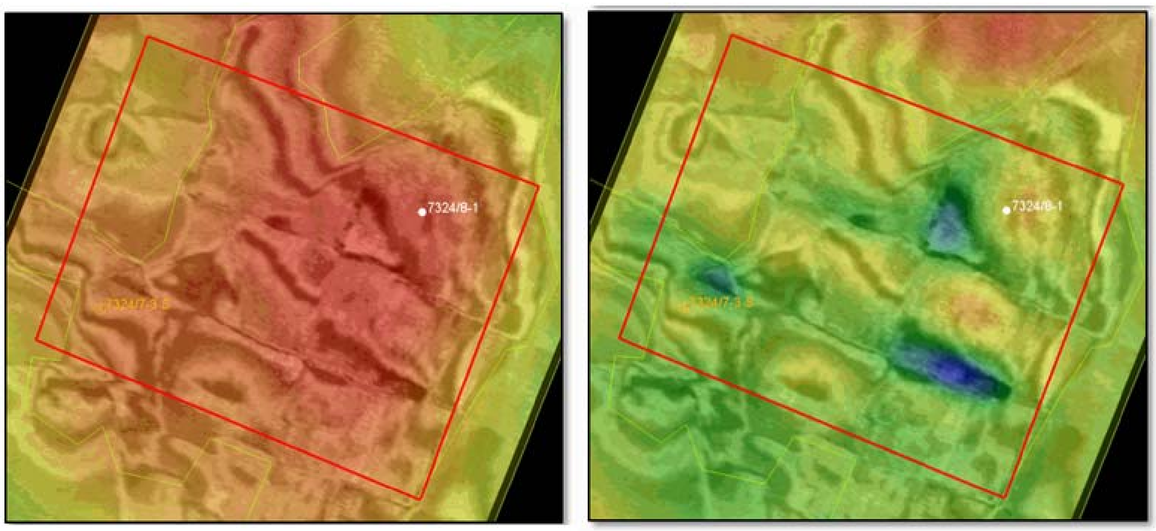

Figure 2 *Left panel: A depth slice at reservoir level showing the the FWI initial model. Right panel: The FWI velocity model after the second frequency band udpate.*

References

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